Sensor Fusion for Intelligent Process Control

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PPG Industries

- Founded in 1883
- More than 100 production facilities worldwide
- Employs more than 31,000 people
- Owned by 90,000 shareholders

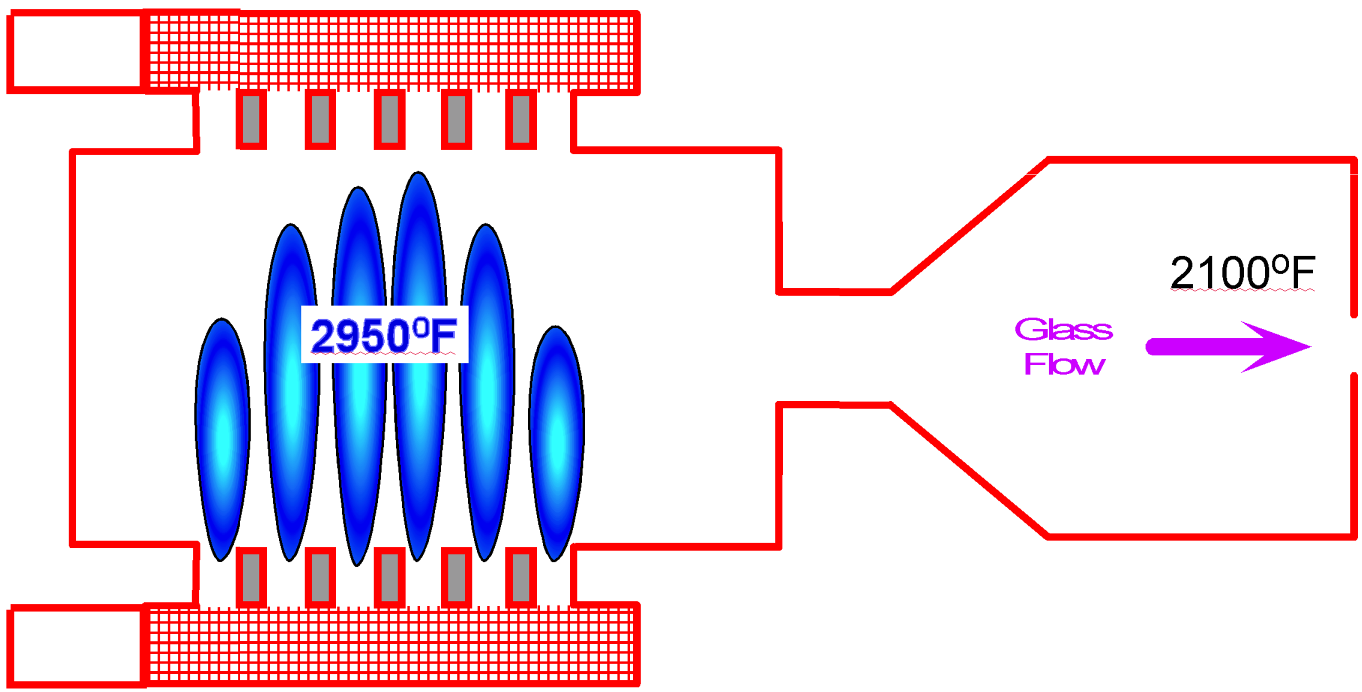
PPG is a Global Producer of:

- Flat and fabricated glass
- Chemicals
- Coatings
- Continuous-strand fiber glass

Typical Soda-Lime Batch

Sand	73%	Silica
Soda Ash	14%	Flux
Dolomite **Limestone**	13%	Weathering Abrasion
Gypsum	.3%	Fining
Rouge	.1- 1.5%	Color and Energy Properties
Selenium **Cobalt** **Titanium**	.03%	Colorants

Tank



How Hot is 2950ºF?

	Melting Point, °F
Ice	32
Plastic	250
Solder	400
Aluminum Pots	1200
Cast Iron Skillet	2150
Concrete	2500
Stainless Steel Knives	2750

Process Overview

- Regenerative cross-fired air/natural gas furnace.
- Process over three tons of nitrogen per ton of glass produced.
- Consumer demands for energy efficient glasses have been met by increasing the iron concentration in the glass. The low IR glasses reduce heat transfer to the glass, which can increase the combustion space temperatures and increases NOx formation.
- Furnace combustion control parameters are optimized for NOx control at the expense of optimizing other process conditions, (product quality, through put, thermal efficiency, and refractory degradation).
- Natural gas is the largest cost contributor in the flat glass manufacturing process.

Goals

•Reduce N0x by 20%.

•Optimize the combustion process to achieve 100% combustion.

•Improve oxygen sensor performance and reliability.

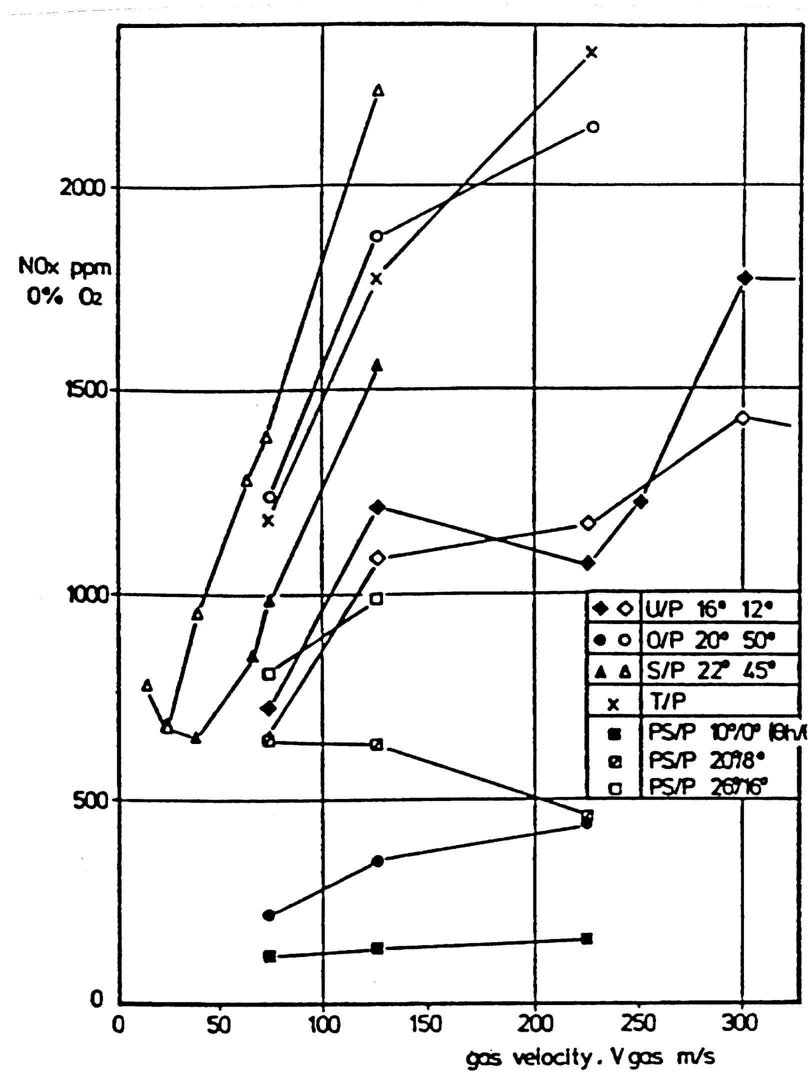
NO_x Highly Sensitive to Fuel Distribution

Measurements at the International Flame Research Foundation (Nakamura, Smart, and van de Kamp, *J. Inst. Energy 69,* 1996, 39-50)

Highest values are associated with gas injection through the port neck.

Lowest values are associated with gas injection into the furnace through the breast wall with minimum penetration of the air jet.

Results suggest opportunities for optimization.



Project Scope

Implement control system to reduce NOx and improve combustion efficiency while maintaining glass quality.

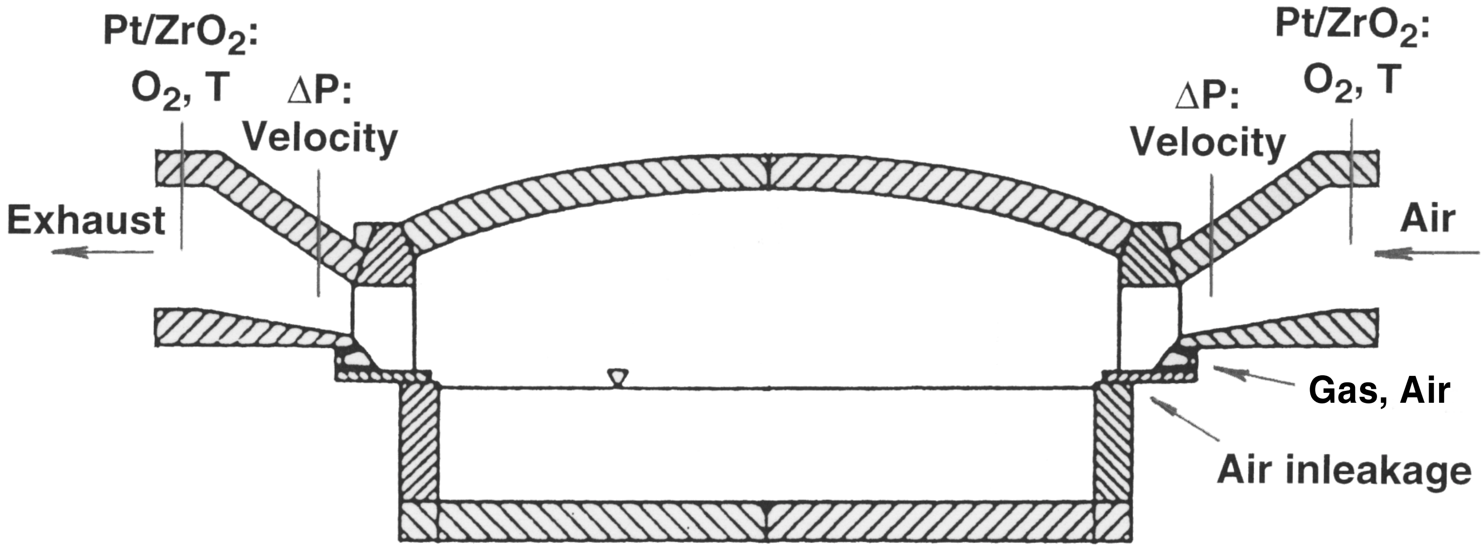
Control heat input and air/fuel ratio on each port.

Use existing sensor technology

- Pt/ZrO_2 probes for oxygen
- Impact probes for gas velocity
- Thermocouples for temperature

Model used to describe the dependence of NOx (single port) on measured conditions.

Control of Air/Fuel Ratio on Individual Ports



Approach:

Adjust gas flows to satisfy temperature requirements.

Add air to optimize air/fuel ratio at each port.

Measurements:

Inlet gas, air, and supplemental air flowrates.

Exhaust flowrates and O_2 contents.

Stack NO_x and SO_2.

Teams

Benchmark

Sandia: Lee Bertram (leader)
PPG: Mark DeYoung, Yu Jiao, John Connors, Rajiv Tiwary

Modeling and Simulation

University of Utah: Philip Smith (leader)
PPG: Rajiv Tiwary, John Connors, Kwang Won, William Haley
Sandia: William Houf

Sensors

Sandia: Peter Walsh (leader)
PPG: John Connors, Mark DeYoung, Ray Farrar, Rajiv Tiwary

Controls

PPG: Yu Jiao (leader), William Haley
Sandia: Robert Hillaire
University of Utah: Dale Smith

Selected Milestones and Decisions

Milestone: Benchmark present performance – 10/31/01

Go/No-go: Assess ability of Pt/ZrO_2 probes to provide reliable and cost effective O_2 measurements – 8/31/01 – if not, select alternative O_2 sensor

Go/No-go: Map gas velocity, composition, and temperature over the entire cross section of an exhaust port to determine whether single point sensing is sufficient – 3/20/02 – if not, adopt alternative approach

Milestone: On-line trial of dynamic model-based NOx predictor completed – 6/30/02

Milestone: Identify data needed to control NOx and combustibles on individual ports and install the indicated sensors and interface – 3/20/03

Milestone: Demonstration of Siemens furnace optimization control system – 12/30/03

Energy Savings

The energy required for melting decreases with increasing throughput.

Reducing NOx formation will permit increased production.

A 2.5% increase in energy efficiency is anticipated.

Implemented over the U.S. glass industry, this would generate energy savings of 0.01 quad/year.

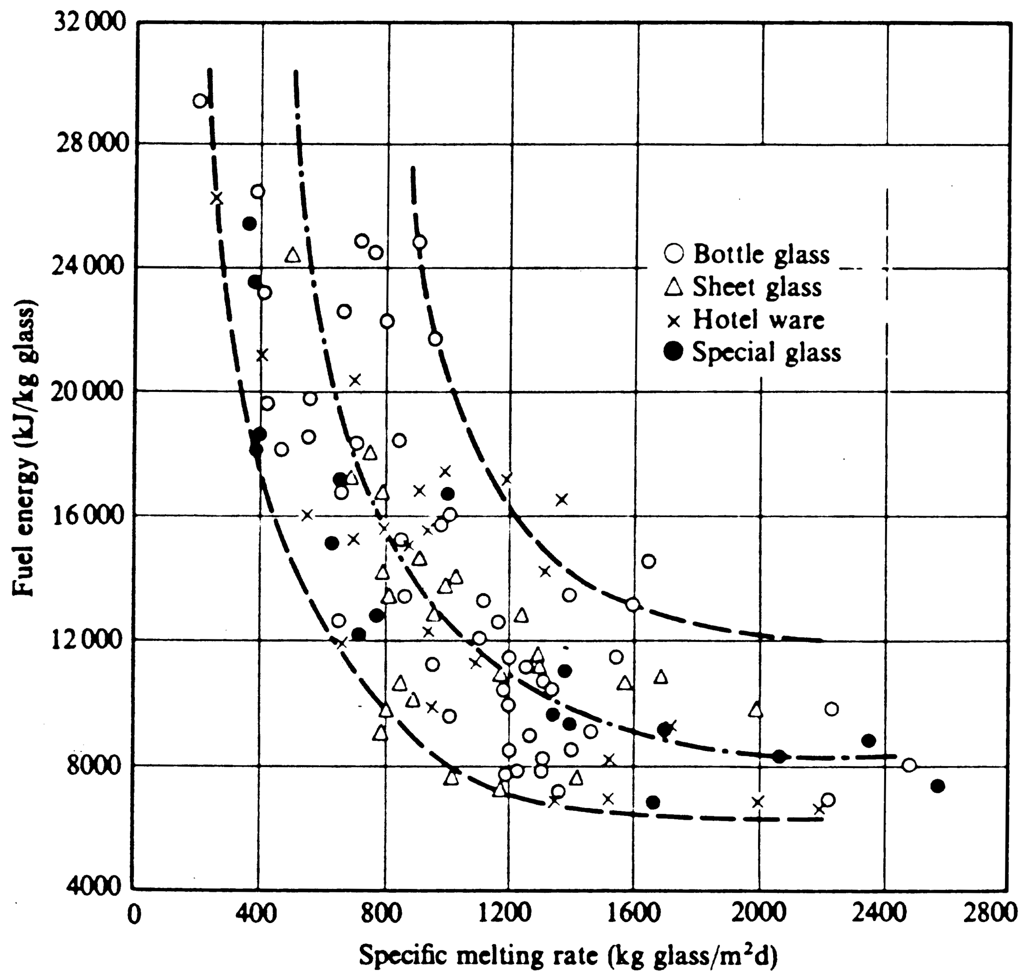


Figure from W. Trier, *Glass Furnaces: Design, Construction, and Operation*, K. L. Lowenstein (Transl.), Society of Glass Technology, 1987.

Crosscutting Applications

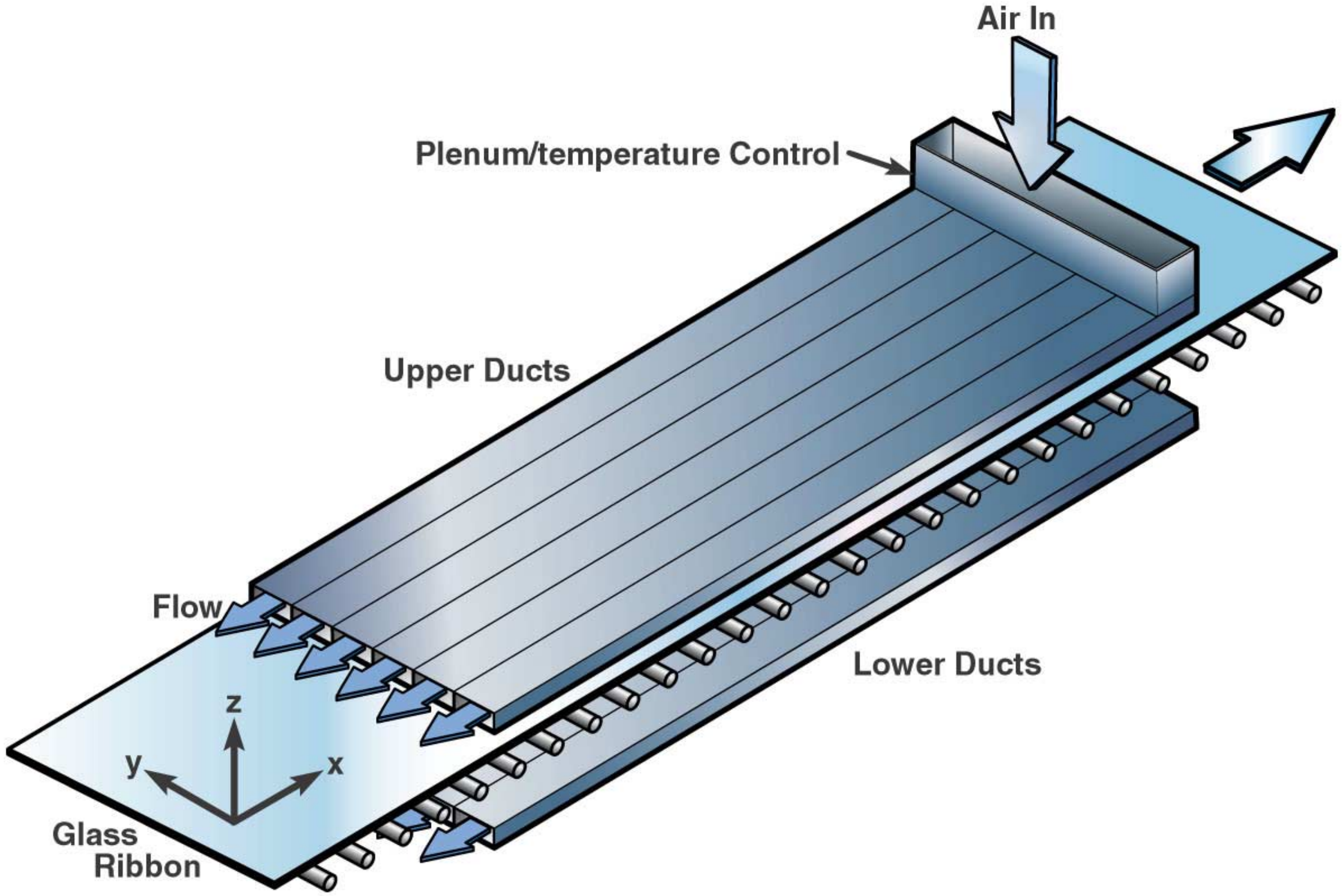
The proposed approach to combustion control is applicable to furnaces fired using multiple burners not having individual combustion air controls and in which the flow from individual burners can be identified with particular locations in the cross section of the flue, such as

Process heaters
Industrial boilers
Reheat furnaces

Project History

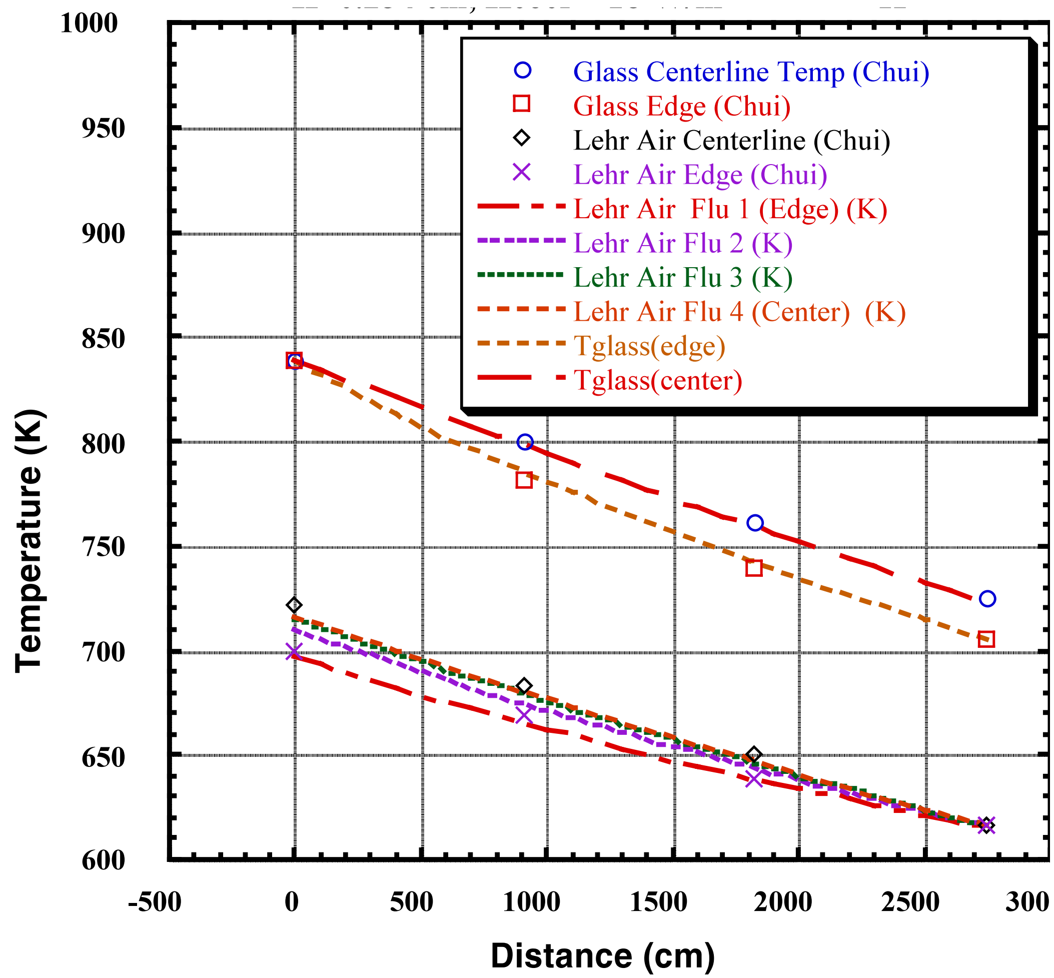
January 1999:	Kickoff meeting of Visteon, Sandia, and Univ. of Utah groups.
February 1999:	Meeting at Visteon Plant in Tulsa, OK. Decision to focus on annealing lehr.
Summer 1999:	Beginning of Visteon reorganization and need to transfer project to new industrial partner.
March 2000:	Report: "Elements for Real Time Steady Simulation of Flat Glass Lehr Control."

Annealing Lehr Heat Transfer Model



Comparison with Results of G. K. Chui*

- **Counterflow annealing lehr of Chui***
  - **16 cooling flues (8 above and 8 below)**
  - **Glass thickness = 0.254 cm**
  - **Glass width = 406 cm**
  - **Glass speed = 211.7 cm/sec**
- **Glass radiation model parameters set to produce Chui's effective emissivity of 0.8**
- **Flue and lehr wall emissivity = 0.9**
- **Flue wall to air h = 18 W/m^{2}K**
- **Model predictions in good agreement with the work of Chui**



* G. K. Chui, "Heat Transfer and Temperature Control in an Annealing Lehr for Float Glass," *Journal of the American Ceramic Society*, Vol. 60, No. 11-12, 1977.

Project History (continued)

March 30, 2000	Kickoff meeting of PPG, Sandia, and Univ. of Utah groups. New focus on combustion control.
March 20-21, 2001	Meeting of PPG, Sandia, and Univ. of Utah groups at PPG Works 14, Mt. Zion, IL. Project goals and teams established.
May 7-8, 2001	Meeting of PPG and Sandia groups at PPG Glass Technology Center.
May 9-10, 2001	Sandia group at Mt. Zion Plant to collect process data and locate sampling points.
May 11, 2001	Meeting of PPG and Univ. of Utah groups at PPG Glass Technology Center.
August 20-24, 2001	Combustion measurements by PPG and Sandia groups at Mt. Zion Plant.